An Interdisciplinary Senior Design Project to Convert Agricultural Residues to Solid Fuel Pellets

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Abstract

In this paper, we present a student design and research project carried out as part of interdisciplinary senior design efforts involving three engineering departments. The main focus of this project was on converting grape pomace to solid fuel pellets for use as an energy source, through the torrefaction process. Environmental engineering (ENV) students investigated the optimum thermochemical conversion protocol to efficiently convert grape pomace into a more useful biomass fuel form; mechanical engineering (ME) students developed specifications for a mechanical and heat transfer system to accept the raw materials and transform them into the finished product; and electrical and computer engineering (ECE) students worked on a control and monitoring system for the purposes of control, command, and monitoring of the entire system. The project team consisted of fourteen undergraduate students (four from ECE, seven from ME, and three from ENV) and three faculty advisors from those departments. Students' performance was assessed within the senior design courses in each department in a form of course exit survey as well as assignments and formal and informal presentations. Overall, the project provided students with great learning opportunities through extensive laboratory experiments and testing, as well as collaborative interaction with an industry partner.

1. Background and Problem Definition

Agricultural residues are those vegetative materials produced around the world that are not useful for their food or other value. One such material produced in the region is grape pomace. Grape pomace is the residual fruit solids remaining after pressing plus the expended filter paper left from the vacuum filtration process used to extract the juice from the press. In rare cases, the pomace can be used as fodder or fertilizer, but in most cases, it is discarded as a waste and must be trucked from the fruit processing plant back to the fields where it decomposes, yielding little benefit to the farmer since it typically contains few nutrients. As one of the nation's grape harvesting regions, the northwest Pennsylvania region produces a large amount of grape pomace, particularly from a Welch's Food, Inc. plant nearby. This single Welch's plant generates about 10,000 tons (wet weight) of grape pomace each harvest. This translates, at 50% moisture content, into about 5,000 tons of dry weight material. This has presented a great opportunity for the engineering students and faculty at Gannon University to work with an important local industry on a hands-on design relevant to addressing real-world issues, that is, study on the torrefaction process[1]-[9] and creation of a system prototype, herein referred to as the *biomass solid fuel generator*.

1.1 Goals and Objectives

The goal of the project was to design a prototype system for the production of a renewable fuel from an agricultural residue, in particular, grape pomace, while contributing to achieving educational objectives of three engineering programs at the University. Toward this goal, the objectives of the project were as follows:

- Objective 1: To determine the optimum thermochemical conversion protocol to efficiently convert grape pomace into a more useful biomass energy form. The form of the fuel would be similar to that of wood pellets and would replace them with a higher energy density.
- Objective 2: To design the mechanical and heat transfer system to accept the raw materials and transform them into the finished product.
- Objective 3: To design a control and monitoring system including on-site data acquisition and transmission of the data to a remote control center for processing for the purposes of control, command, and monitoring of the entire system.

1.2 Design Approaches

The design of the intended system was interdisciplinary in nature. As the starting point for the system design, the students from the Department of Environmental Science and Engineering conducted preparatory research and developed a set of design requirements for the biomass solid fuel generator. The findings of the ENV team were then supplied to the Mechanical Engineering senior design students as well as to the Electrical and Computer Engineering team.

More specifically, senior design students in the Department of Environmental Science and Engineering studied the thermochemical transformation of grape pomace into fuel pellets. The first step was to determine the physical and chemical characteristics of the raw feedstock, and then to determine the time and temperature regime necessary to dry the feedstock given the physical nature of the material. Thus, the amount of energy required for drying could be calculated. Next, working with dried material, the thermal breakdown of the material was studied. The energy density and physical characteristics of the product material was determined for a variety of time and temperature heating protocols. The optimum protocol was identified in order to transform the material to the desired physical form while retaining the maximum possible energy content.

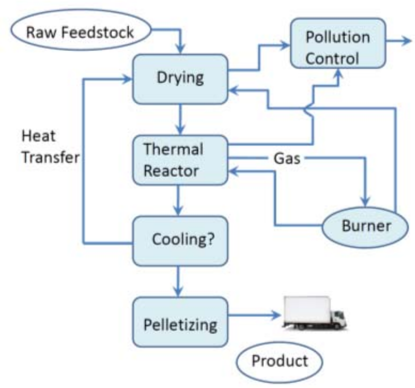

Figure 1. Block diagram of thermal system to convert fibrous plant material into pelletized fuel.

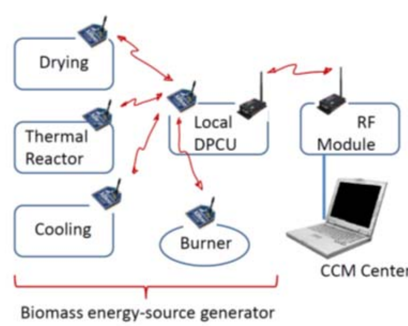

Figure 2. Wireless CCM subsystem.

The block diagram in Figure 1 shows the major mechanical components expected to exist in the biomass solid fuel generator. The ME students detailed design requirements and made recommendations on subsystems and components as well as the necessary interfacial components.

For the *command, control and monitoring subsystem, a* group of senior students from the ECE department considered various data acquisition devices and sensors. Short- and long-range (2.4 GHz and 900 MHz frequency band, respectively) wireless communication and networking devices on the market were examined and integrated for the delivery of the sensor data collected to a laboratory at the University where a software-based control, command, and monitoring (CCM) center would monitor the system located at a remote site. The CCM center was implemented within LabView[10] which was a graphical programming environment for development of sophisticated measurement, test, and control systems. This CCM center was hosted on a computer running on MS Windows 7. Figure 2 shows the conceptual diagram of data delivery from major units of the biomass solid fuel generator.

2. Expected Benefits of the Project

2.1 Relationship to Real-World Issues

The project encompasses several aspects of promoting sustainable environmental protection, economic prosperity, and social benefit. The intended end-users of the outcomes from the project, particularly the pellets, are agricultural processors such as Welch's and every-day people using biomass-based fuels as an energy source. Typically, grape pomace is hauled back to the fields where it decomposes, and supplies little in the way of nutrients to the soil. If the pomace could be effectively and efficiently converted to an energy source, the outcomes of the project would contribute substantially to the preservation of natural environments by replacing the consumption of traditional sources of energy with energy derived from a waste material. Especially, if extended to other agricultural residues, this approach could enhance the profitability of agriculture in the US and would create new markets and jobs related to production, distribution, and consumption of the new energy source!

An ultimate success of the project could be celebrated in a form of "BBQ party" using the pellets from the *biomass solid fuel generator*. Such demonstration of use of the new energy sources would increase general public's awareness of sustainability. Another group of end users of the project is college students who directly participate in the project and also those who learn about the project while at the University. When the outcomes of the project are shared with a larger group of students at the University in various forms and events, the potential and benefits of educating the young generation, especially college students, is huge. It can be further envisioned for the longer term that the biomass solid fuel generator could serve as a framework for new "service learning," addressing "humanitarian technology challenge" around the world[11]. A technology-based, sustainable, environmentally benign solid fuel generator should be a good tool for these purposes as well as addressing environmental issues in a larger scope involving people in under-developed countries.

The project could contribute to ultimately creating new markets pertinent to production, distribution, and consumption of the pellets from grape pomace or similar feedstock. However, as a small-scale proof-of-concept project, it was premature to properly estimate long-term costs of the product although short-term costs to develop a small-scale prototype were estimated for the purpose of the project.

It is noted that there is a growing industry in the US to produce wood pellets for use in home and industrial heating. However, wood pellet manufacturers prefer high quality small logs and generally do not utilize woody debris or other fibrous residues. Thus, wood pellet production falls far short of full utilization of forest resources and does not at all address the full utilization of agricultural residues. The burning of wood for heat is a notorious air polluter. Due to the distributed and small nature of these burners, they are largely unregulated. In our project approach, it was anticipated that the pomace-pellets would burn much cleaner, thus reducing the mass of air pollutants emitted to the atmosphere. Considering the small size of the prototype envisioned in this project, proper air pollution control systems may not be feasible, but would necessarily be part of a full-scale version of the pellet producing system. The pellet-producing system would be a regulated source, and thus would contribute to an improvement in air quality, especially in rural areas where wood burning is particularly common.

The project was also expected to have little or no negative impact on the local environment. The current practice at the Welch's plant in the region is to truck the pomace back to the vineyards from which it came, or any other location that agrees to take it. This creates a significant expense for Welch's. Also, when the material is dumped from the truck at the destination, the farmer must spread the material quickly or it will begin to anaerobically decompose producing noxious odors. This places an economic and time-consuming burden on the local farmers and potentially creates bad will among the neighbors if odors do result. If all of the pomace was processed into fuel pellets, there would be a complete beneficial change in the management of this agricultural waste.

2.2 Challenges to Creating Multidisciplinary Student Teams

The project was carried out primarily by undergraduate seniors from three departments in the School of Engineering and Computer Science at the University: ENV, ME, and ECE departments. All student design activities were part of their respective senior design courses in the three engineering departments.

Even though the Engineering Accreditation Commission of ABET mandates that engineering programs demonstrate that students achieve "(d) ability to function on multidisciplinary teams," most senior design projects at our institution are discipline specific. Although the ECE department actively promotes interdisciplinary projects and collaboration among students from its two programs, computer engineering and electrical engineering it is in general challenging for all projects to be interdisciplinary. When planning an interdisciplinary senior design experience among three engineering departments, there were significant institutionalized obstacles to be overcome. It was quickly realized that even the timing and structure of the senior design courses among the three departments were not aligned.

For example, ENV students begin their design experience with the fall semester of their senior year, and are expected to spend that semester developing a project topic and producing a 'design proposal' by the end of the semester. The design work is then conducted during the spring semester and the final work product is a design report and presentation at the end of the semester. Rarely was any actual device or process constructed or utilized by the students.

On the other hand, at the time of this project, ME students began their design experience with a junior-year spring-semester seminar, during which the students identified projects and began the initial planning for their projects, which would be executed during the fall semester of their senior year and were finished with the project by the end of that semester. These projects typically involved actually building a working device of some sort.

The senior design sequence for ECE students spanned the fall and spring semesters of the senior year as did for the ENV students, but they were typically expected to construct and present a working prototype system that would typically include electrical/electronic hardware and/or software components and subsystems of some sort. There was some discussion about also inviting senior business students to participate in the project, but the incompatibilities that existed between the business curriculum and the engineering programs were so great that such an idea was abandoned quickly after a conversation with the business school director.

The senior design courses met at different times of the week. Therefore, it was inconvenient for the students from all three programs to meet as a team and at no time did all the students and faculty involved meet in one room at the same time. On several occasions, the faculty mentor and individual students from a department were able to attend class sessions for the other programs. Communications were therefore of necessity by email.

As the academic year unfolded, the synchronization of the work of the three groups deteriorated further, and they ended up working independently. Once the spring semester began, the ME students were finished with their requirement and were no longer interested in the actual construction of the prototype. Work proceeded at the plastics recycling site mainly through the efforts of the ENV and ECE students. While this was disappointing, the work was successful and torrified material was actually produced by the students. Later in the spring, a number of these students were able to travel to Washington, DC, to participate in the EPA's P3 Expo on the National Mall held in April, and share the project's outcomes with the public. Student efforts on the project activities leading to such a trip with an appropriate level of preparation for participation in such a huge event were highly commended. Learning experience from such project activities and event were substantial.

3. Data, Findings, and Outcomes

The project activities of the ENV team included studying the requirements for a system capable of converting a variety of organic feedstocks via a torrefaction process into a pelletized fuel similar in heating value to bituminous coal. The feedstocks of interest were primarily grape pomace but also included horse manure and waste dog food. These particular feedstocks are generated in sufficiently large quantities in the region to make them candidates for an industrial-scale operation. The Presque Isle Downs Racetrack and Casino, located in the region, generates about 2,250 tons of horse manure and soiled bedding over a roughly six-month period; the Purina Mills dog food plant located near Dunkirk, NY, produces about 4,000 tons per year of rejected dry dog food which is currently disposed of in a landfill; and the Welch's Foods bottling plants located in the region produce about 15,000 tons of grape pomace each fall during the grape harvest. Each potential feedstock has a unique chemical composition, moisture content, physical structure, and pattern of availability.

3.1 System Prototype

The creation of a proof of concept prototype of the biomass solid fuel generator has evolved as well, as it drew a serious interest from a local company. The company became interested in the concept. As such, with the company's donation of surplus equipment such as a 7-ft tall hopper and a plastics extrusion unit, the team decided to modify the donated equipment to the purpose of the project. Subsequently, a prototype system (see Figure 3) was constructed at the recycling facility operated by a division of the Company to demonstrate the feasibility of the concept and to provide processed material for further testing. Experience building and operating the prototype system provided a basis for improvements to the design. Assistance was provided by the company's personnel with funding from the US EPA and the Ben Franklin Technology Partners of Central and Northern Pennsylvania.

Figure 3. Prototype system under development.

3.2 Laboratory Methods for Torrefaction Process

3.2.1. Feedstock Samples for Laboratory Processing and Testing

Grape Pomace: Grape pomace was collected directly from the Welch's Foods pressing system while still warm and placed in plastic zip-lock bags. The bags were placed in an ice chest with crushed ice for transport to the laboratory. At the lab, the sample bags were placed in a freezer until removed for use. The grape pomace consisted of seeds, stems, skins, and filter paper fiber from the juice pressing system (Figure 4).

Horse Manure: The horse manure samples used for this project were obtained from a nearby boarding stable. The samples were collected from freshly deposited feces and transported to the laboratory in zip-lock bags. Separately, samples of sawdust bedding material were also collected in a similar fashion.

Figure 4. Raw Grape Pomace.

Dry Dog Food: A bag of Purina Mills "Puppy Chow" was obtained from a local supermarket. Since each type of dog food manufactured contains slightly different ingredients, additional samples needed to be obtained (as further testing called for during the remainder of the project period).

3.2.2. Preparation of Raw Material

Drying: Prior to torrefaction, the feedstock needs to be completely dry so as to prevent the creation of water vapor in the torrefaction vessel. Drying time is a function of temperature, particle size, and surface area. The feedstock for this project was thawed from a frozen state and then weighed in a 500mL Pyrex beaker to obtain the wet weight of the material. The beaker with the material was then placed in a drying oven at 105 °C for various lengths of time. The beaker was then weighed and the weight recorded. After weighing, the beaker was placed back into the drying oven and weighed again after another time interval. This process continued until there was no change in weight.

Homogenization: The dried feedstock was processed in a knife mill for a period of two minutes to reduce particle size and generate samples as representative of the bulk material as possible.

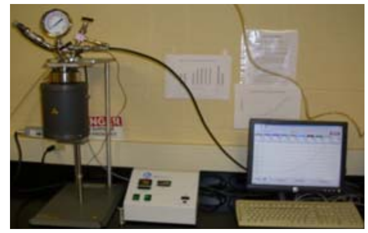

Figure 5. Parr Instruments, Inc., pressure vessel equipped with electronic controller and personal computer.

3.2.3. Torrefaction of Dry Material

Bench-top Thermal Reactor: The thermal reactor (Figure 5) used for laboratory torrefaction of materials for this project was a stainless steel pressure vessel by the Parr Instrument Company, with an internal volume of 600 mL. The vessel was manufactured to withstand a maximum temperature of 500 °C and 2000 psi. The heating mantle, thermistor, and pressure transducer were connected to a programmable electronic controller which itself was connected to a personal computer for data acquisition and storage. The thermal chamber contained a glass liner within which the sample material was placed. An inlet valve led to a tube which extended to near the bottom of the vessel and was used to flush the chamber with pure nitrogen for at least five minutes to remove oxygen from the system. The outlet valve if open allowed the gaseous contents of the system to be exhausted or collected, or could be closed to seal the system.

3.2.4. Procedure for Torrefaction

A portion (typically 15 g) of dried and ground feedstock material was placed in the glass liner whose empty weight was known and recorded. Once the steel vessel was assembled and secured, the system was purged with pure nitrogen for at least five minutes to remove oxygen from the system. The desired target temperature was set using the Parr controller. Temperature and pressure over time was acquired and stored by the controller and software running on the attached computer. Temperature control by the system was not perfect and an oscillation was observed around the temperature set point. The highest temperature actually reached was recorded. Temperature was maintained for a period of time, typically 15 minutes, and the heating system was then turned off. The heating mantle was lowered and the vessel was allowed to cool. The glass liner was then removed and weighed to determine the amount of mass remaining. Material was removed for further examination.

3.2.5. Off-gas Collection

The reactor could be operated with the outlet valve either open or closed. If closed, the pressure would increase during the heating run due to both expansion of the contained gases and the production of new gases. Upon cooling, the outlet valve was opened and the generated off-gases were collected in a gas sampling bag (Flexfilm VOC sample bags by SKC, Inc.) for measurement of volume and composition (detailed descriptions are omitted due to the limited space). Alternatively, the outlet valve could be left open and a collection bag attached to the outlet tubing. In this case, atmospheric pressure was maintained inside the reaction vessel and gases could be collected during various time or temperature intervals. Since these off-gases were generated at a variety of temperatures, an adjustment to the volume measurement using the Ideal Gas Law was necessary to account for simple expansion due to heating.

Figure 6. Pellet die for lab pelletization.

3.2.6. Laboratory Pelletization of Torrified Material

To analyze the energy density and the friability of the torrified material, pellets were created (Figure 6). The pellet press consisted of a small round die, two metallic disks, and a metallic dowel rod. Torrified material was loaded into the die, and then compressed to 1500 psi with a hand operated hydraulic press.

3.2.7. Bomb Calorimetry

Figure 7. Bomb calorimeter.

A bomb calorimeter (Figure 7) by Parr Instruments was used to measure the energy content of the pelletized material according to the standard method for the instrument.

3.2.8. Friability Testing

Three replicate pellets of cooled torrified material were created using the hydraulic pellet press and weighed after formation. Each pellet was placed in a tumbler for 30 minutes, rotating at 8 rpm. The pellets were then removed and weighed again, and the percent weight lost during tumbling gave a rough idea of the friability of the pellets. This is of relative value only to suggest whether torrefaction under one time and temperature routine resulted in material that formed better pellets than under a different time and temperature routine.

3.3 Feedstock Analysis Results

3.3.1. Initial Moisture Content of Feedstocks

The average water content for 10 samples of horse manure was 76 % (solids content = 24%). Of the dry weight, the portion that was volatile (organic) was 93%, leaving ash of 7% (equivalent to 1.7% of the original wet weight). For grape pomace, the mean moisture content was 55%, and for dog food directly from the bag, the moisture content was 12%.

3.3.2. Mass Yield upon Torrefaction

The biomass after torrefaction consists mainly of three phases: a solid bio-char, a fluid tar-like material, and non-condensable gases. Production of the tar-like material was not quantified during this project, but appeared to increase as a fraction of the total end products as the temperature of treatment was increased. Generally, as the temperature increased, the mass yield decreased. The time of treatment had little effect on the mass yield.

- Grape Pomace: The mass yield after torrefaction of grape pomace above a temperature of 200º C was between 75 and 90%. It appeared that the yield stabilized in the 260º to 300º C range (Figure 8).

- Horse Manure: The mass yield for horse manure samples varied from about 95% at a mild 220° C to a low of less than 50% at 400° C (Figure 9). Increasing the time of treatment at 220° C from 5 minutes to 30 minutes did not appreciably increase the loss of mass. A pronounced loss in mass occurred when the torrefaction temperature was increased above 250° C and then again above 320° C.

- Dry Dog Food: The mass yield for dog food was close to 100% until the torrefaction temperature exceeded 200 C. At that point there was a steady decrease in yield as the temperature increased such that the yield was about 70% at 300º C (Figure 10).

3.3.3. Energy Density after Torrefaction

- Horse Manure: Treatment at the mild temperature of 220° C, regardless of time of treatment, improved the energy density of the horse manure samples only modestly. However, when the temperature of treatment was increased to 280 °C, the energy density was increased above that of lignite coal and approached that of bituminous coal (Data figures omitted due to the limited space).

- Grape Pomace: Upon torrefaction to a temperature in the range of 260 to 280 °C, the energy density of grape pomace exceeded that of bituminous coal (Figure 11). The energy density of grape pomace increased at lower temperatures (200 °C) compared to the raw material and compared to the other feed stocks.

- Dry Dog Food: The energy density of

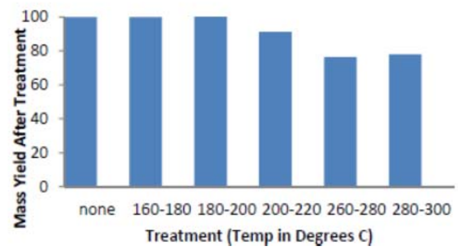

Figure 8. Mass yield after torrefaction of grape pomace.

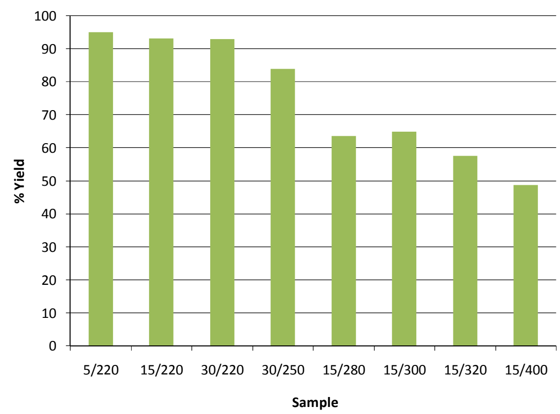

Figure 9. Mass yield of horse manure after torrefaction. * The horizontal axis indicates the time (min.) and temperature (C) of treatment.

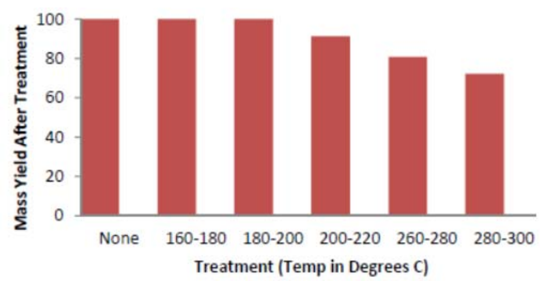

Figure 10. Mass yield after torrefaction of dog food.

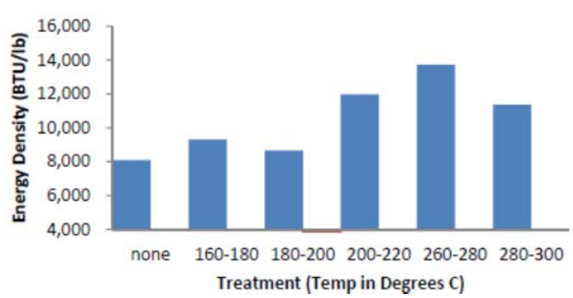

Figure 11. Energy density of grape pomace after torrefaction at various temperatures.

terrified dog food increased with treatment temperature, but did not exceed 10,000 BTU/lb until the treatment temperature reached the 280 to 300 °C range (Data figures omitted due to the limited space).

3.3.4. Energy Yield upon Torrefaction

Energy yield is a function of both energy density and mass yield, and is the energy content of the final material divided by the energy content of the starting material. It turns out that very little energy is lost during this process, and what is lost is contained in the off-gases generated during heating. For example, for most runs, the energy yield was greater than 90%.

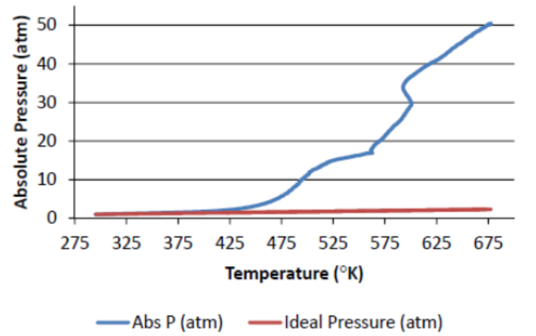

Figure 12. Pressure as a function of temperature during a torrefaction run up to 400°C (675° K). * The reverse slope just above 30 atm indicates that gases were being generated even though the temperature declined momentarily. Note: Red line indicates pressure that would be due to gas expansion only as predicted by the Ideal Gas Law if there was no gas generation.

3.3.5. Gases Generated during Torrefaction

Gas generation increased with temperature treatment. The highest treatment temperature investigated was 400 °C (752 °F). Using data from a torrefaction run to 400 °C, pressure is shown as a function of temperature rather than time (Figure 12). The horizontal axis in the figure is presented in degrees K (degrees C plus 273) since that temperature scale is based on absolute zero and the Ideal Gas Law is a function of Absolute Temperature. The pressure began to deviate from that which would be expected due to expansion alone at approximately 400°K and continued a climb steadily until the treatment was over at 673°K. This was interpreted as being due to the generation of off-gases.

3.3.6. Friability of Pellets

Figure 13 presents a comparison of mass lost during tumbling for untreated horse manure and torrified horse manure after various levels of treatment. The untreated horse manure pellet lost 15% of its mass during the friability test. The samples that were treated at 220°C lost roughly 2% of their mass during tumbling. At temperatures of 250°C and above, the % of mass lost per pellet was less than 2%.

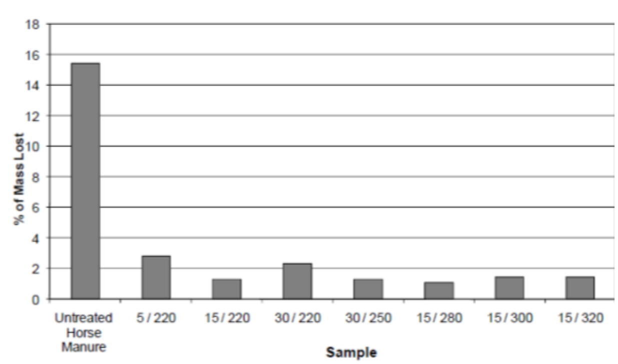

Figure 13. Percent of mass lost from horse manure pellet sample during the friability test. On the horizontal axis, the samples are expressed as time (min.)/temperature (C).

3.4 Command, Control, and Monitoring

As initially planned as shown in Figure 2, the Command, Control, and Monitoring (CCM) is implemented with three major subsystem components: 1) four K-type temperature sensors with each sensor interfaced with an XBee 1mW Communication Module, 2) a

Cerebot MX3cK Microchip PIC32 32-bit MIPS processor from Diligent Inc. for the local Data Processing and Control Unit (DPCU) with an XBee 1mW Communication Module and an RF 900MHz modem with RS232 interface, and 3) the Command, Control, and Monitoring (CCM) Center with an RF 900MHz modem with RS232 interface. Communication between the DPCU and sensor nodes is carried out via 2.4 MHz wireless connection, and the communication between the DPCU and the CCM is carried out via 900 MHz wireless connection.

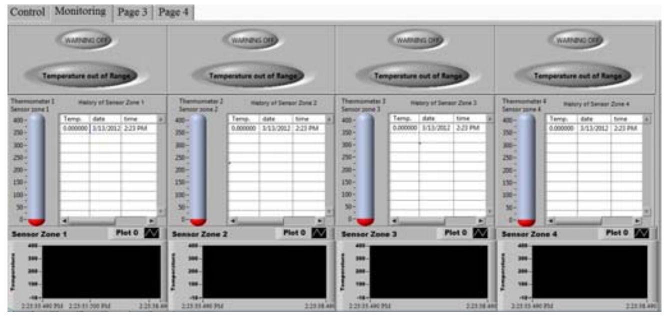

Figure 14. A snapshot of the Monitoring screen of the CCM

For the main interface to monitor the biomass solid-fuel generator status, the Graphical User Interface (GUI) is designed to display sensor data in real time at every 10 seconds for the four sensors (and saved to an Excel file as necessary). An alert mechanism is also implemented to generate a warning sign as a button turning red when the temperature monitored exceeds the predetermined thresholds suitable for the drying process and torrefaction process. Also, functionality for control operations is implemented within the GUI but in a separate screen page. Figure 14 and Figure 15 show a snapshot of the Monitoring and Control screen, respectively. This GUI runs on Windows 7 and can be deployed as stand-alone software on personal computers without a full LabView package.

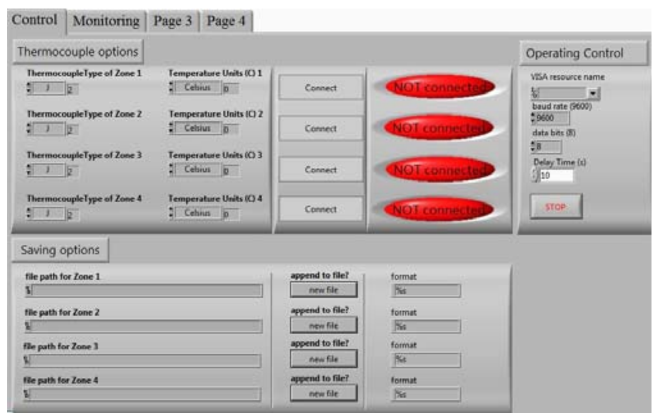

Figure 15. A snapshot of the Control screen of the CCM

4. Assessment of Student Learning Outcomes

Student learning outcomes were assessed throughout the project duration in each department as part of its own senior design course. As in senior design courses at most institutions, the student learning outcomes in the senior design in the three departments typically were assessed on some of the key '*a thru k'* ABET-defined student learning outcomes such as a) ability to apply knowledge of mathematics, science, and engineering, b) ability to design and conduct experiments, c) ability to design a system, component, or process to meet desired needs, d) ability to function on multidisciplinary teams, f) understanding of professional and ethical responsibility, g) ability to communicate effectively, i) recognition of the need for, and an ability to engage in life-long learning, as well as department-specific outcomes such as i) develop systems containing hardware & software components and ii) analysis & design (A&D) of complex electrical & electronic devices. Also, some of the liberal art-related learning objectives set by the University were also assessed particularly on the ability to communicate effectively both written and verbal, and demonstrate successful learning for the speech-related objectives including 1) be able to relate the theories and practice of non-verbal communication, 2) recognize and be able to integrate the Aristotelian principles of Ethos, Pathos, and Logos into the performance plan, 3) be able to utilize non-verbal communication strategies (movement, stance, facial expression, and gesture) to enhance the delivered message, and 4) synthesize the use of various vocal techniques to create meaningful messages.

The ABET-defined and department-specific student learning outcomes were assessed based on course-specific deliverables of the senior design courses such as requirements specifications, project concept design document, functional decomposition, project management plan including a Gantt chart and a bill of materials, test plan, and a design specifications document (in the end of the 1st semester) and a final project report (in the end of the 2nd semester). Although students in each department were mostly responsible for the subsystems falling in their discipline areas, these deliverables were deemed reasonable indicators of effectiveness in student learning.

On the liberal arts-related and communication-skills related outcomes, assessments were conducted based on student team's participation in various oral presentations within their department. Such events are typically offered at least twice in a semester including final oral presentations in fall and spring semesters, and IEEE student paper competition (ECE-specific) in spring with external judges as part of the preparation for IEEE Region 2's Student Activities Conference.

Finally, a Course Exit Survey was given in the end of each semester to collect student's assessment on their learning and course itself. All of the assessments indicated that students learning experience was great, including positive reflections of their experience in traveling to Washington, DC, as part of the project team, to participate in the US EPA-sponsored expo.

5. Discussion, Conclusions, Recommendations

It was found that the energy yield upon torrefaction was more than 90% of untorrified energy content and loss in mass per pellet was less than 2%. The overall conversion efficiency from wet-weight biomass material to ultimate pellet would be subject to further refinement, but it appeared that dry weight could directly translate into the mass of the biomass energy source, the pellet. This means an overall yield of 1.7% of the original wet horse manure, 45% of wet grape pomace, and 88% of dog food. The ultimate environmental impact would require more complicated calculation taking into account, no need to dispose waste (positive), energy consumption during the process (negative), environmental impact of gases generated during the process (negative), and commercial applicability and its impact (positive).

The project was successful in that, 1) with extensive laboratory experiments and testing, it clearly identified the torrefaction process for the grape pomace as well as two additional materials, 2) it progressed as planned to build a system prototype with a pleasantly surprising donation of what would be high-cost materials, and 3) it progressed well to design a complete end-to-end command, control, and monitoring subsystem. However, it was yet to be successful in that, the project as a whole was incomplete by an original completion date. The donation of the physical prototype materials was critical as well as the in-house availability of the necessary laboratory equipment, not to mention the dedication of the student team members to the project efforts.

All three engineering departments substantially contributed their expertise to the overall success of the project. Evident from the interests from local industry and the State government's technology driver, Ben Franklin Technology Partners, the project does have great potential to make positive impacts in making progress toward sustainability. Our experience with creating interdisciplinary teams led to changes in the structure and timing or our senior design course sequences. After the disappointments of what could have been closer and more constructive coordination among the entire team members from different departments, the three departments agreed to synchronize the course scheduling. The ME department transitioned to a fall-spring senior-year course sequence rather than the current spring-fall sequence beginning during the junior year. Also, the three departments agreed on a common meeting time for the senior design courses in order to facilitate interaction among the students. We look forward to more interdisciplinary projects in our continuing efforts to achieve the goal of ABET's EAC Outcomes, particularly on team work, (d): an ability to function on multidisciplinary teams.

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